

Biochar Systems for Sustainable Agriculture

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VISIT...

LANZAROTE
Caliente.COM

- The many possible uses of biochar
- The relevance of soil: EU policies
- Introduction to biochar production technologies
- Biochar characteristics
- Biochar to offset GHG emissions
- Biochar integrated to sustainable agriculture
- Biochar and Anaerobic Digestion



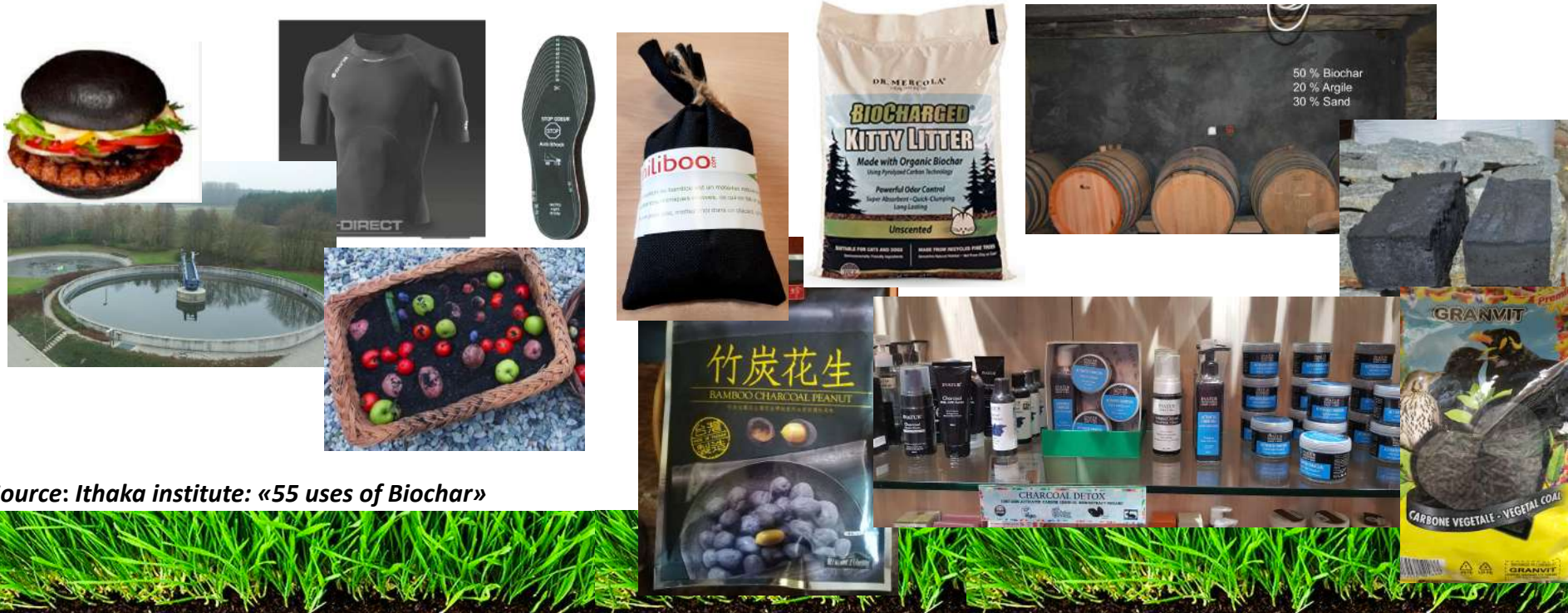
Biochar is a “*multiple-win*” approach, as it

- can be produced by **many (incl.residual) feedstocks & various processes**
- is a **mature technology**, available in a **wide range of scales**, generating solid material (fuel/amendment) + high temperature renewable heat
- sequesters large amount of long-term **stable recalcitrant C**
- supports **sustainable** (more organic, less fossil) **agriculture** & well matches with cover cropping, catch cropping/agroforestry, conservation agric., etc
- is a key solution for **poor/marginal land** recovery → adaptation to Climate Change → **food & feed + energy/materials (e.g water treatment)**
- well combines with **AD** and **digestate** use/**composting**



→ **A cost-competitive decentralized solution enabling sustainable agriculture & developing local/rural economy**

- ✓ *Animal Feed, Biogas/Biomethane, Metallurgy, Buildings, Water Treatment, Air Treatment, Textiles, Food, Preserving, Colour, Medicine, Cosmetics, Electronics, Batteries, Industrial Materials, Dessiccant, etc..*



Source: Ithaka institute: «55 uses of Biochar»

→ We will focus on Biochar use in sustainable agriculture

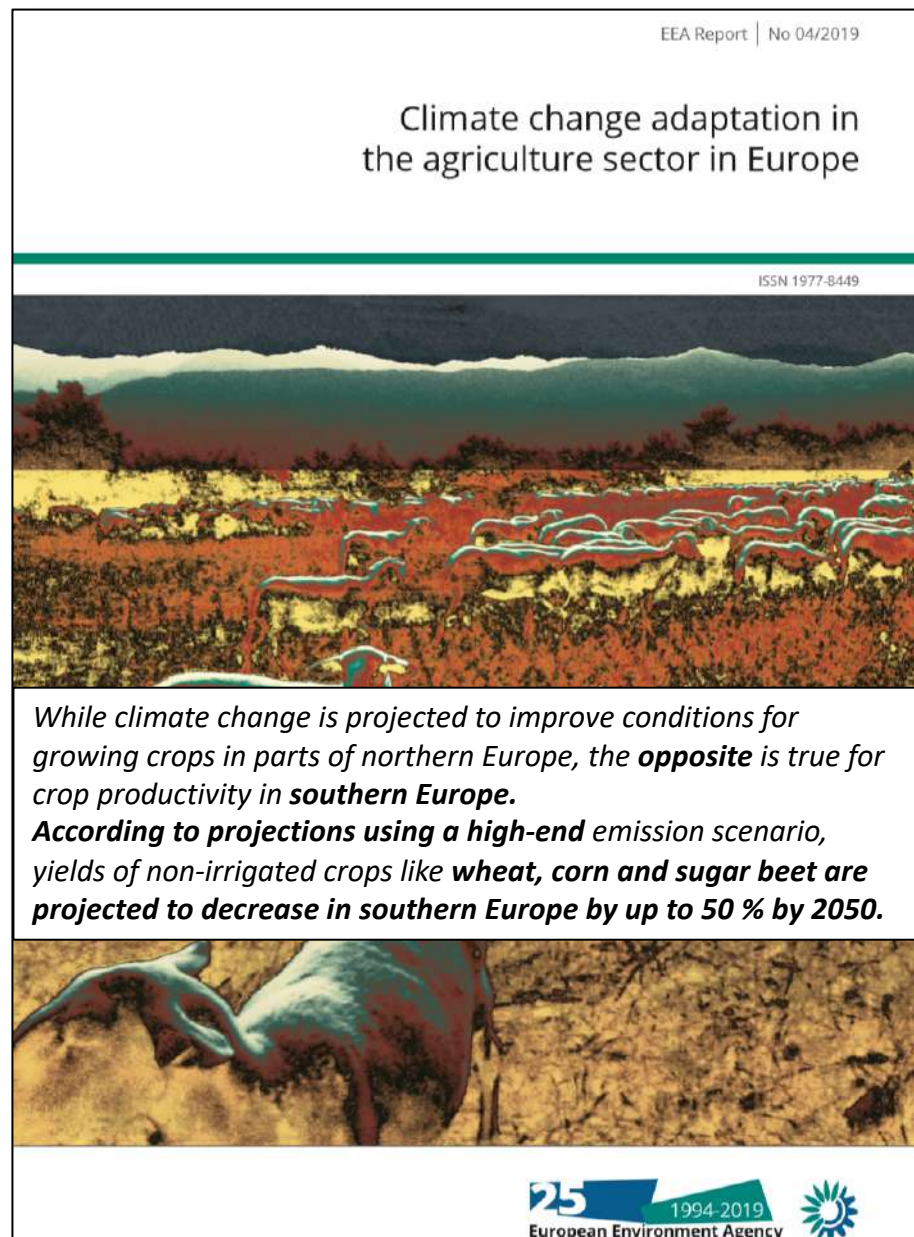


SOIL: THE URGENT NEED TO TAKE ACTION



V. [...] **no EU-level strategy on desertification and land degradation**. Rather, there is a range of strategies, action plans and spending programmes, such as the Common Agricultural Policy, the EU Forest Strategy, or the EU strategy on adaptation to climate change, which are relevant to combating desertification, but which do not focus on it.

[...] we make recommendations to the Commission aimed at better understanding land degradation and desertification in the EU; assessing the need to enhance the EU legal framework for soil; and stepping up efforts towards delivering the **commitment** made by the EU and the Member States to achieve **land degradation neutrality in the EU by 2030**.



While climate change is projected to improve conditions for growing crops in parts of northern Europe, the **opposite** is true for crop productivity in **southern Europe**.

According to projections using a high-end emission scenario, yields of non-irrigated crops like wheat, corn and sugar beet are projected to decrease in southern Europe by up to 50 % by 2050.



Soil and C in REDII and EU Green Deal



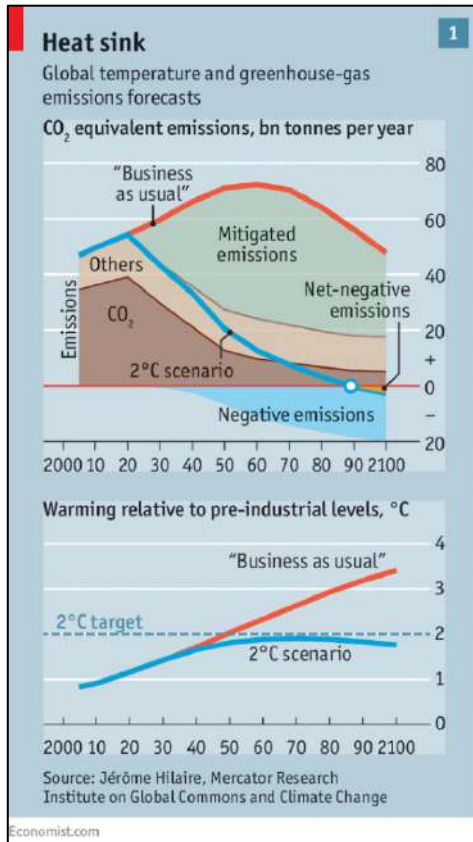
The European Green Deal



- **Healthy soil:** essential for food/feed, sustainable bioenergy and bioeconomy
- **REDII** includes C-in-soil measurements (Annex V)
- **EU Mission on Soil** (https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme/mission-area-soil-health-and-food_en)
- Soil is a key component in the new **EU Green Deal** (part of 6 in 9 EU Green Deal goals) and **UN SDGs**



THE 2° PARIS GOAL REQUIRES C-NEGATIVE ACTIONS



The Economist

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Sucking up carbon

Greenhouse gases must be scrubbed from the air

Cutting emissions will not be enough to keep global warming in check

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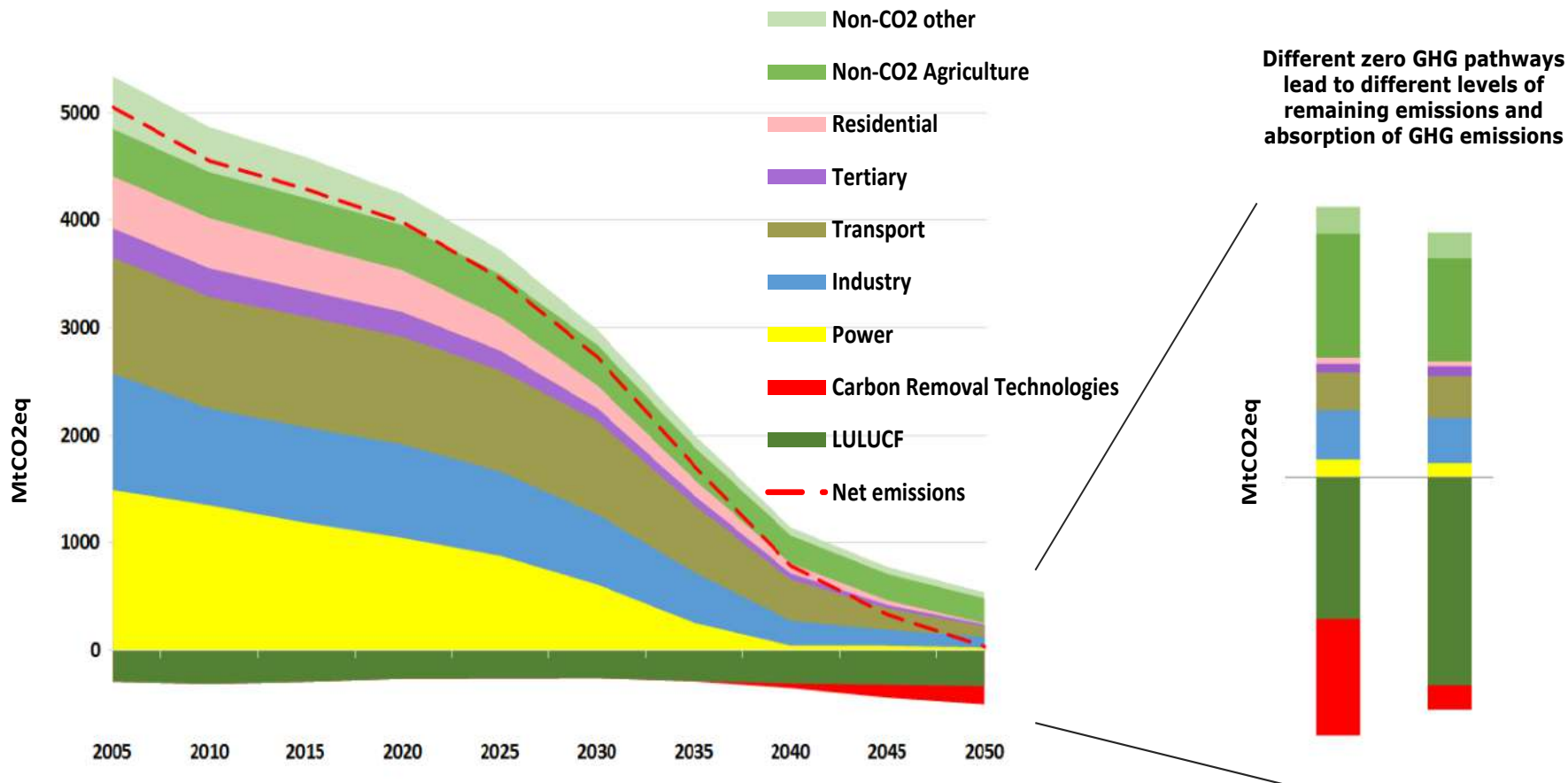
[...] No scenarios are at all likely to keep warming under 1.5°C without greenhouse-gas removal. "It is built into the assumptions of the Paris agreement," Gideon Henderson, Oxford University. [...] COP23, Bonn.



THE DECARBONISATION PATHWAY IN THE EU



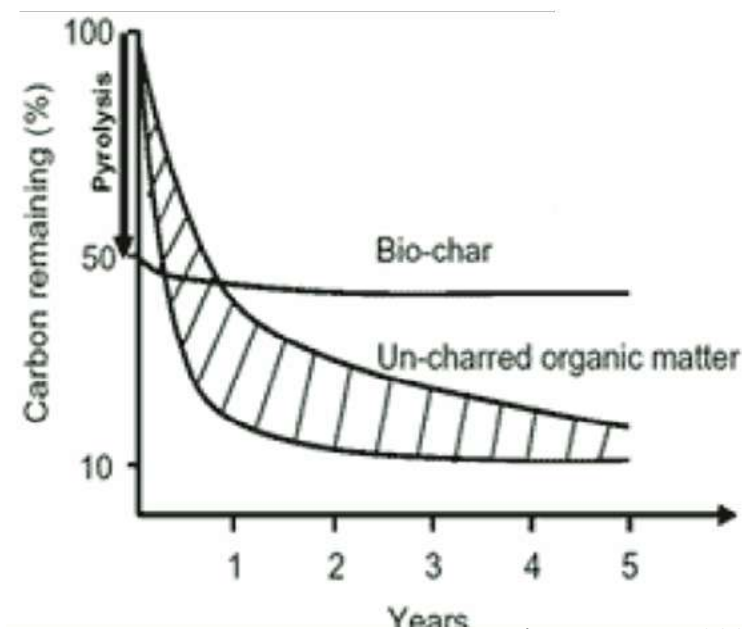
GHG emission trajectory for 1.5 °C



Source: A Clean Planet for All, EC

SOLID PRODUCT

FROM THERMOCHEMICAL CONVERSION OF BIOMASS FEEDSTOCKS



(J. Lehmann, 2006)

HIGH CONTENT IN RECALCITRANT C

LARGE POTENTIAL FOR C SEQUESTRATION AND STORAGE IN SOILS



Cubic Foot Bags



BIOCHAR AS SOIL AMENDMENT AND FOR SLOW N-RELEASE

- *Terra Preta* (Central America) is a well-known example in Biochar
- But also EU has been engaged in biochar for long time
- **Justus Von Liebig** (1803-1873), “father” of organic chemistry
- Liebig questioned the prevailing theory that humus or black soil was essential for plant growth because it imparted a vital life force to plants. Believers in humus thought that the black soil contained an organic life force or “vitalism” that could not be derived from dead, inorganic chemicals. This theory was based on the well-known fact that “virgin” soil from recently cleared forests was black and fertile.
- He also stated: “[..] *But how inferior is the agriculture of Europe to that of China!* [..]”

Source: *The Biochar Journal*



TO FARMERS.

POUDRETTE! POUDRETTE!!

The LODI MANUFACTURING COMPANY (the oldest manufacturers of Fertilizers in the United States) offer their celebrated Poudrette for sale at lower prices than any other fertilizer in market.

It is made from the night soil and offal of New York City, and has been in use by thousands of farmers for over a quarter of a century: it will manure an Acre of Corn in the hill, and increase the yield one third.

A Pamphlet with the experience in its use on Lawns, Garden Vegetables, Corn, Potatoes, and Tobacco, of hundreds of Farmers, some of whom have used it for over 20 years, containing also price, directions for use, &c., will be sent free to any person applying.

LODI MANUFACTURING CO.,
66 Courtlandt Street, New York.

Liebig recommended, “calcined mud and finely divided charcoal as additives to retain nitrogen (Agric.Chem., p 66)

[..] charcoal “surpasses all other substances in the power which it possesses of condensing ammonia within its pores... it absorbs 90 times its volume of ammoniacal gas, which may be again separated by simply moistening it with water.” (Agricultural Chemistry, p 35.)



THE PYROLYSIS PROCESS

THERMOCHEMICAL DECOMPOSITION (CONVERSION) OF ORGANIC MATERIALS
THROUGH HEATING IN COMPLETELY ANAEROBIC CONDITIONS

PRODUCTS OF
THERMOCHEMICAL
CONVERSION

SOLID



Charcoal

LIQUID

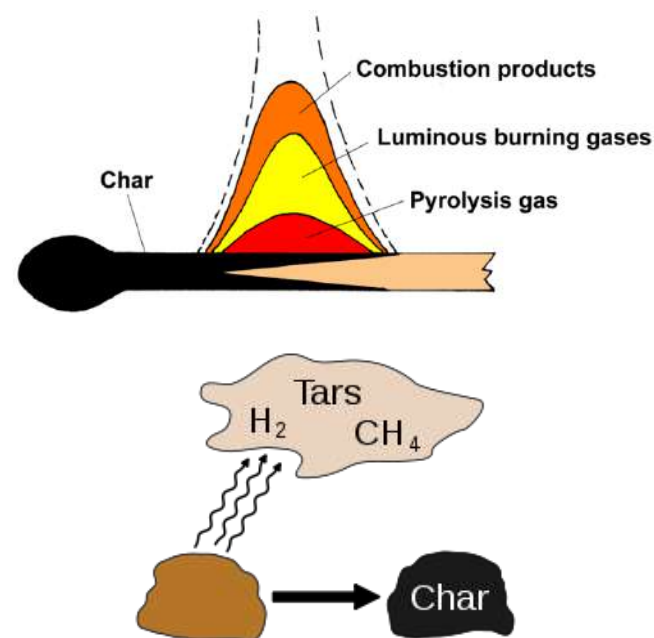
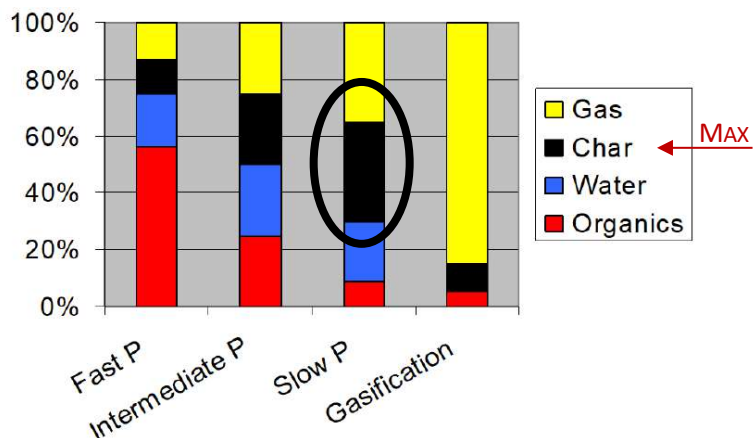


Bio-oil

GAS



Pyrogas



SLOW PYROLYSIS

TYPICAL PROCESS TEMPERATURE: $400 \div 600 \text{ }^{\circ}\text{C}$

LONG RESIDENCE TIME OF SOLIDS AND VAPORS

LOW HEATING RATE: $0,1 \div 2 \text{ }^{\circ}\text{C s}^{-1}$

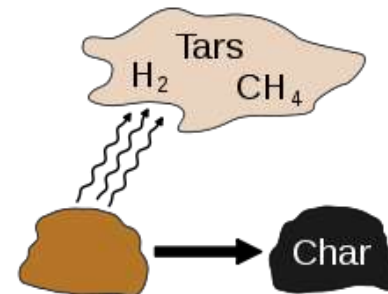
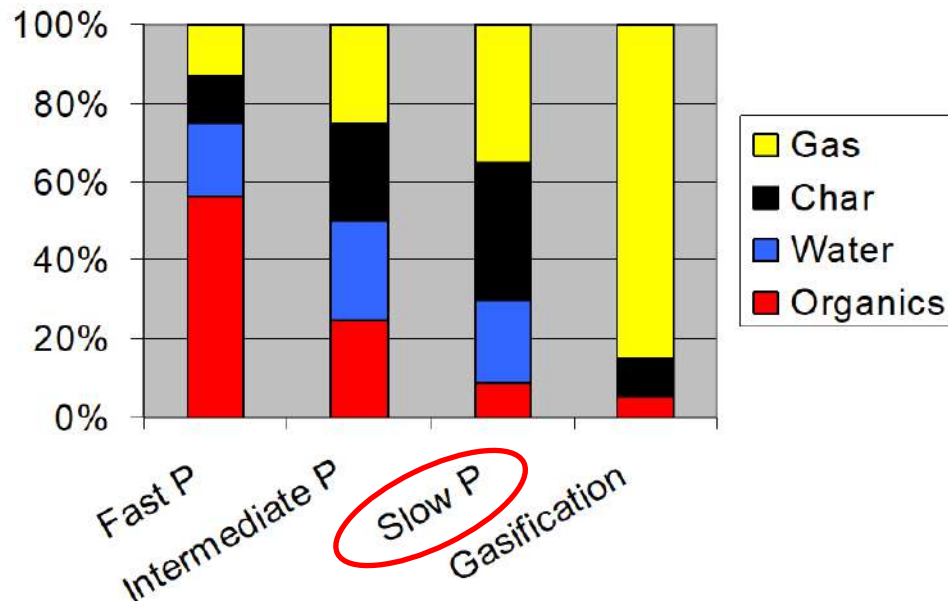
PRODUCTS $\rightarrow$ CHAR + BIO-OIL + GAS

BIOCHAR PRODUCTION TECHNOLOGIES



Biochar is a products of Thermochemical Biomass Conversion

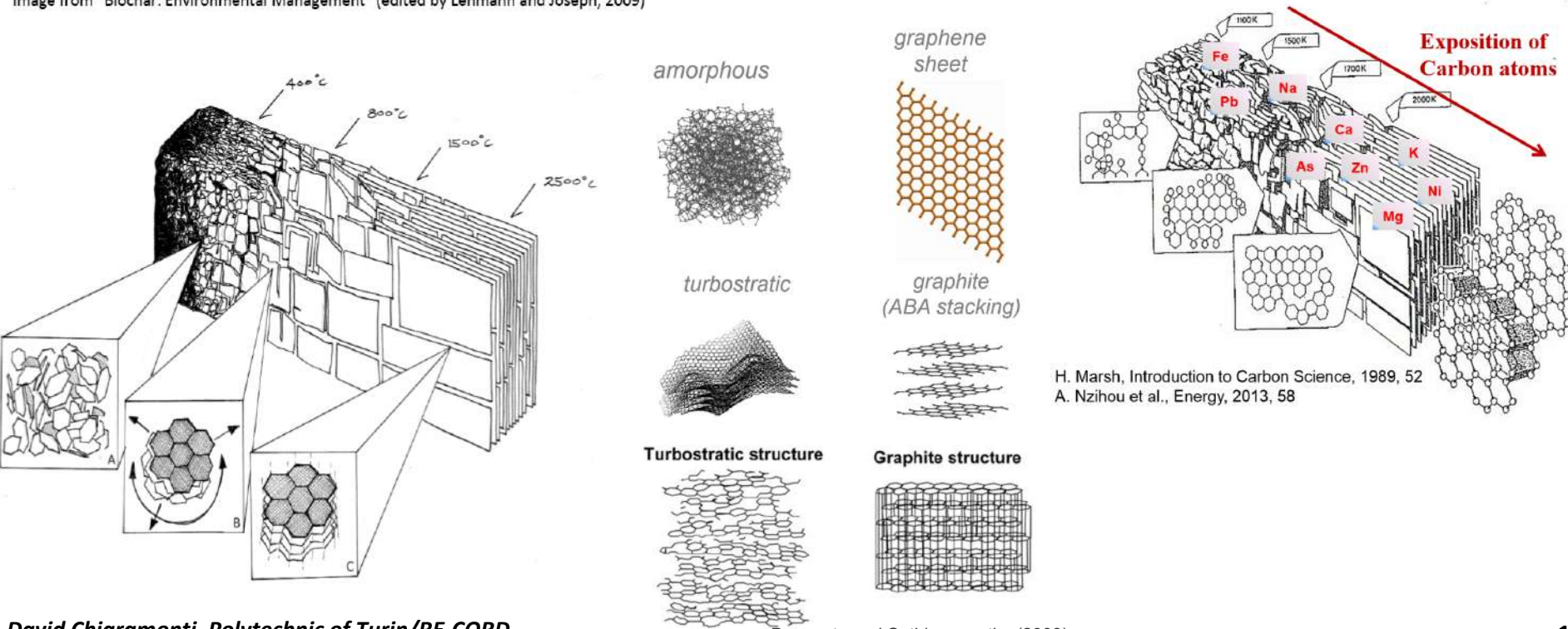
- Pyrolysis (Flow, Fast), Gasification, Hydrothermal Carbonisation
- Biochar is the **main product of SLOW Pyrolysis**, that also produces High-Temperature Renewable Heat
- **SLOW Pyrolysis**: very robust and mature technology. Many reactor types available at any size.
- A Multi-Feedstock technology



UNDERSTANDING THE CHAR STRUCTURE IS KEY FOR APPROPRIATE PRODUCTION AND USE

- 130-140 °C: Release of water and steam extraction of VOCs
- 140-400 °C: Hemicellulose degrades, Cellulose-lignin bonds break down
- 400-600°C: Main Pyrolysis reactions, massive pyrogas release
- 600-800 °C: Aromatic frames development
- 800-2500 °C: Turbostratic rearrangement, towards graphene sheet

Image from "Biochar: Environmental Management" (edited by Lehmann and Joseph, 2009)

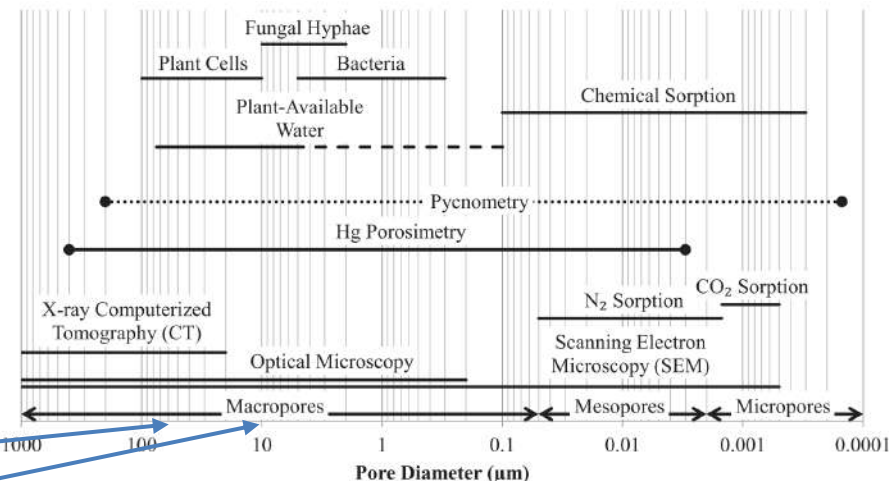
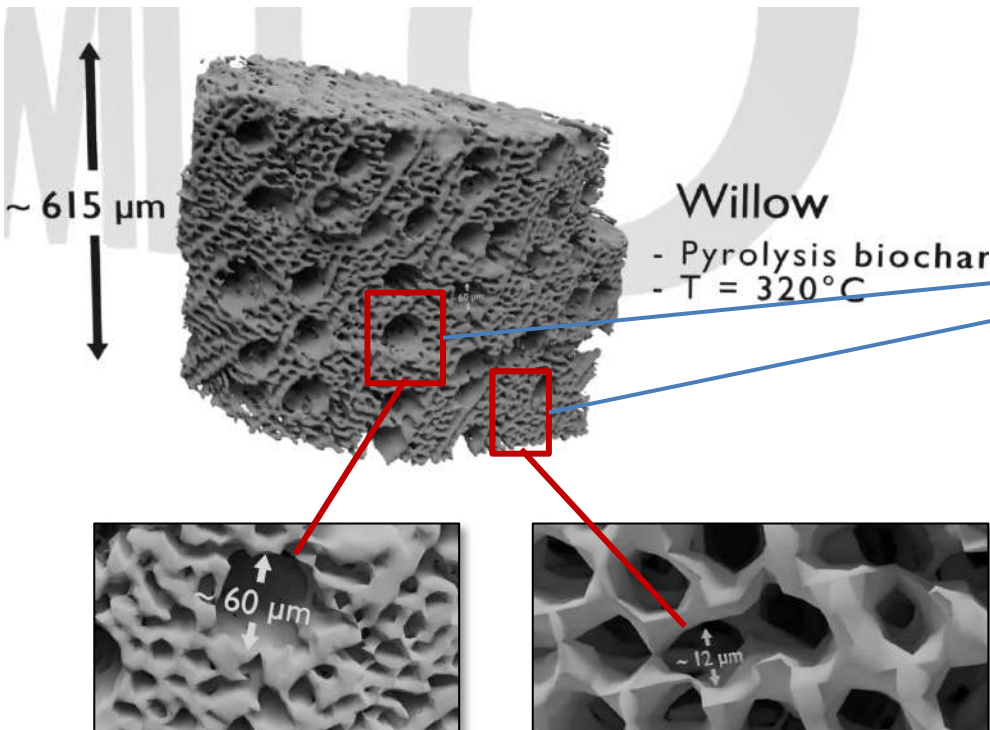




SPECIFIC SURFACE, WATER RETENTION CAPACITY....



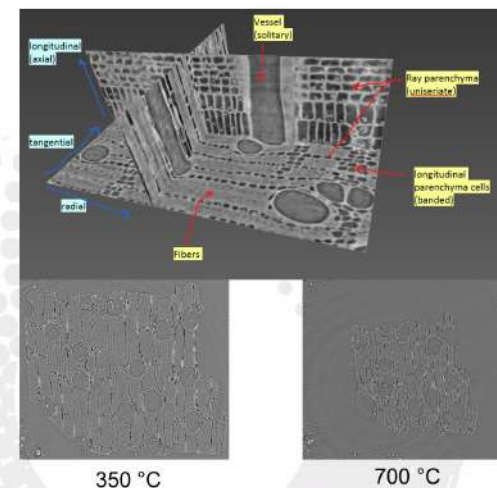
Source: Luke, Finland. X-ray tomographic reconstruction of a willow biochar sample pyrolysed at temperature 320 °C. Image resolution is 1.14 μm . Camera moves through pores relevant for water retention (approx. 10 and 50 μm in diameter). <https://www.youtube.com/watch?v=xZeu8mNlxZQ>



Brewer CE, et al., New approaches to measuring biochar density and porosity, *Biomass and Bioenergy* (2014), <http://dx.doi.org/10.1016/j.biombioe.2014.03.059>



Biochar structure engineering



Biochar from raw wood



Biochar from pelleted wood

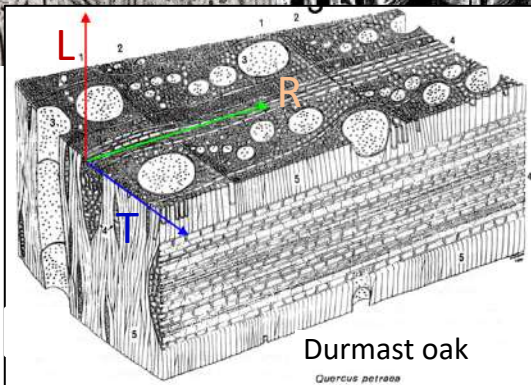
O. Masek et al., 3rd E2S2-CREATE Biochar Workshop, 16th January 2019, Singapore

WOOD STRUCTURE: HARDWOOD/SOFTWOOD

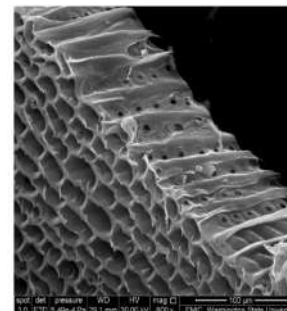
Hardwood *Angiosperms-Monocotyledons*

Softwood *Coniferous*

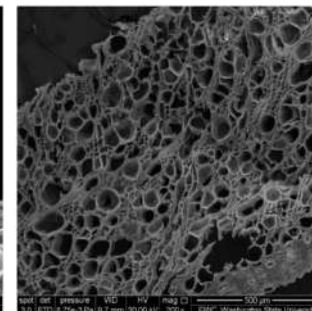
Biochar structure depends on
feedstock characteristics + technology + process conditions



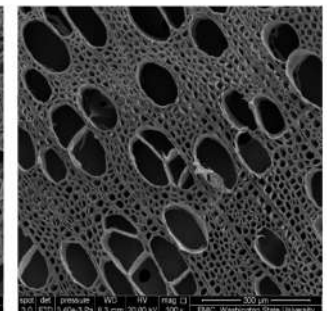
Source: Marco Togni, DEISTAF, University of Florence



Pine wood biochar
mag. 800X



Pine bark biochar
mag. 200X

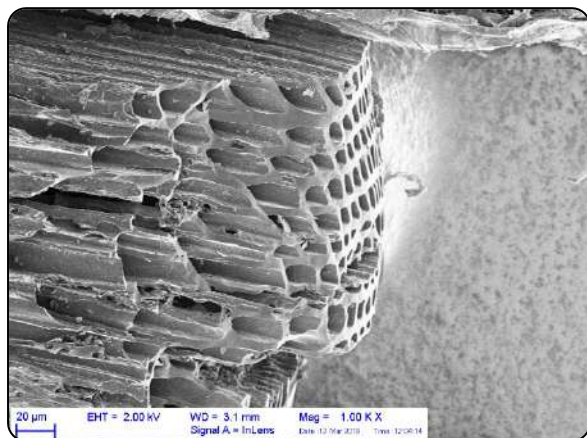


Poplar wood biochar
mag. 300X

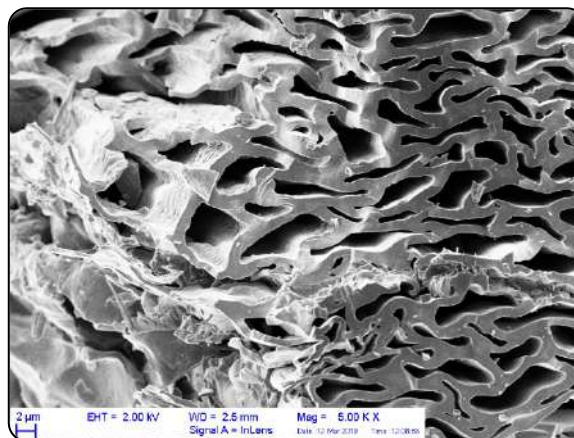
Suliman WSO, Harsh J, Abu-Lail N, Fortuna A-M, Dallmeyer I, Garcia-Perez M: Influence of Feedstock Source and Pyrolysis Temperature on Biochar Bulk and Surface Properties. *Biomass and Bioenergy*, Volume 84, 2016, pp 37-48

AGRONOMIC CHARACTERISTICS OF BIOCHAR

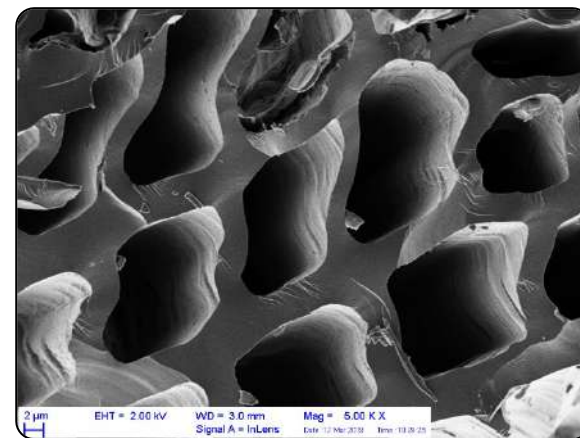
- **HIGH POROSITY (MICRO-, MESO- E MACRO- PORES):**



SLOW PYROLYSIS OF BLACK PINE – 1000X

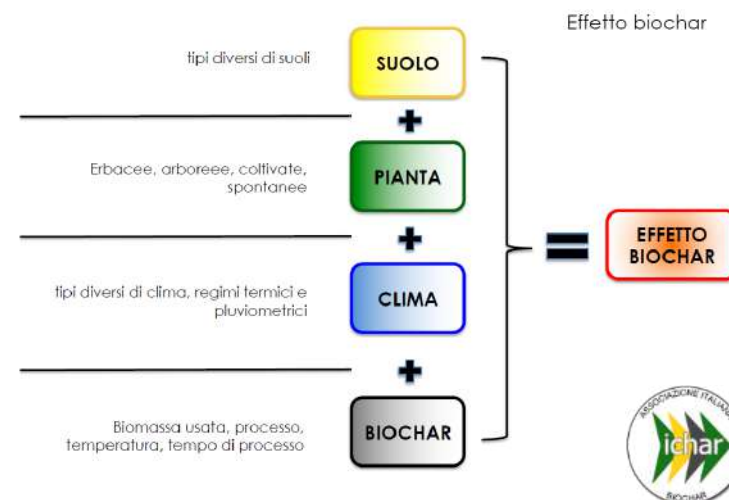


SLOW PYROLYSIS OF POPLAR – 5000X



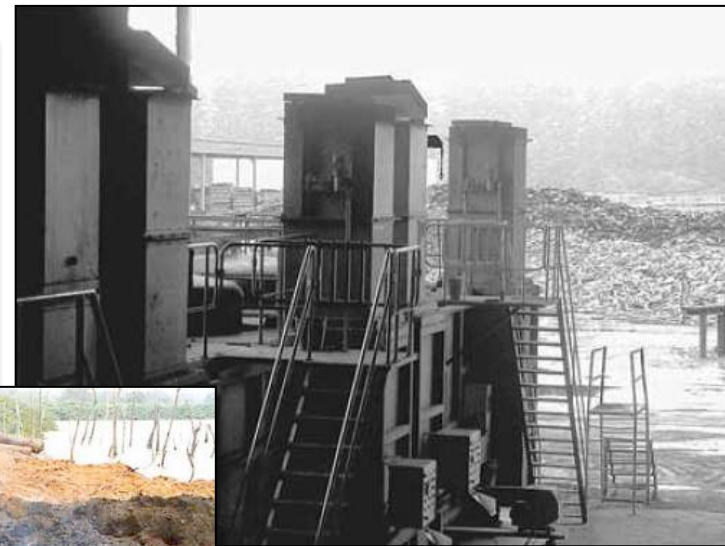
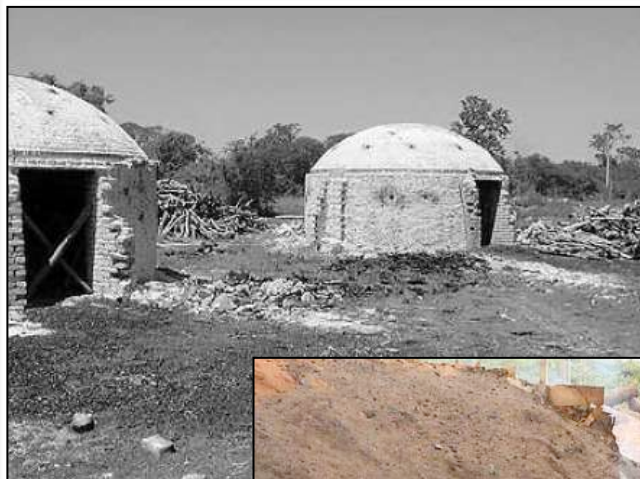
SLOW PYROLYSIS OF POPLAR – 10000X

- **HIGH MOISTURE RETENTION CAPACITY**
- **HIGH POTENTIAL TO LIMIT LEACHING OF NUTRIENTS**
- **SUITABLE HABITAT FOR MICROORGANISM GROWTH**
- **HIGH REACTIVE SURFACE, WITH REACTIVE FUNCTIONAL GROUPS (CEC AND AEC)**

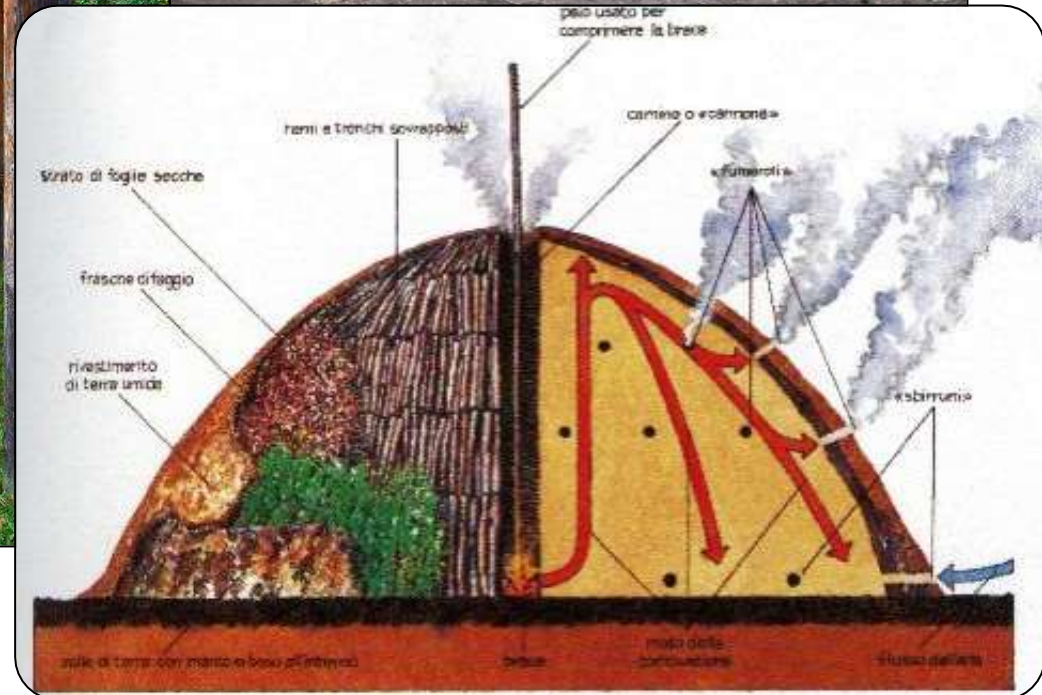
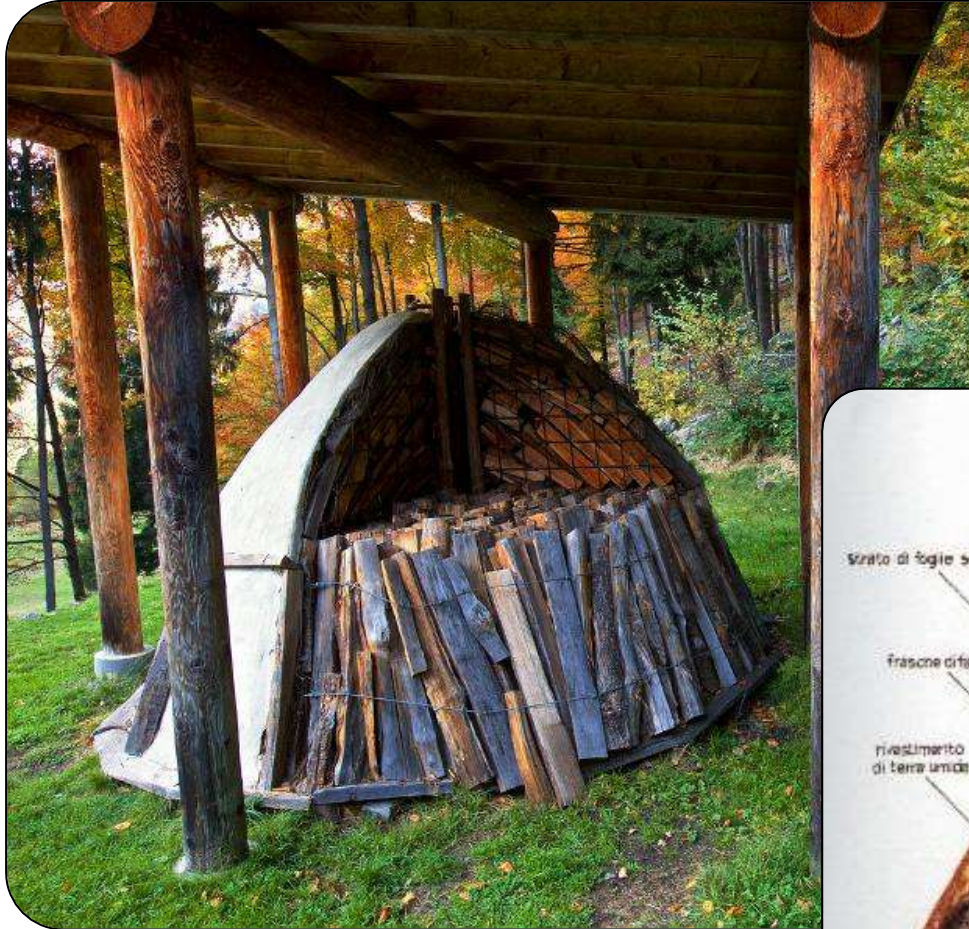




Charcoal production: traditional systems



EU TRADITIONAL CHARCOAL MAKING

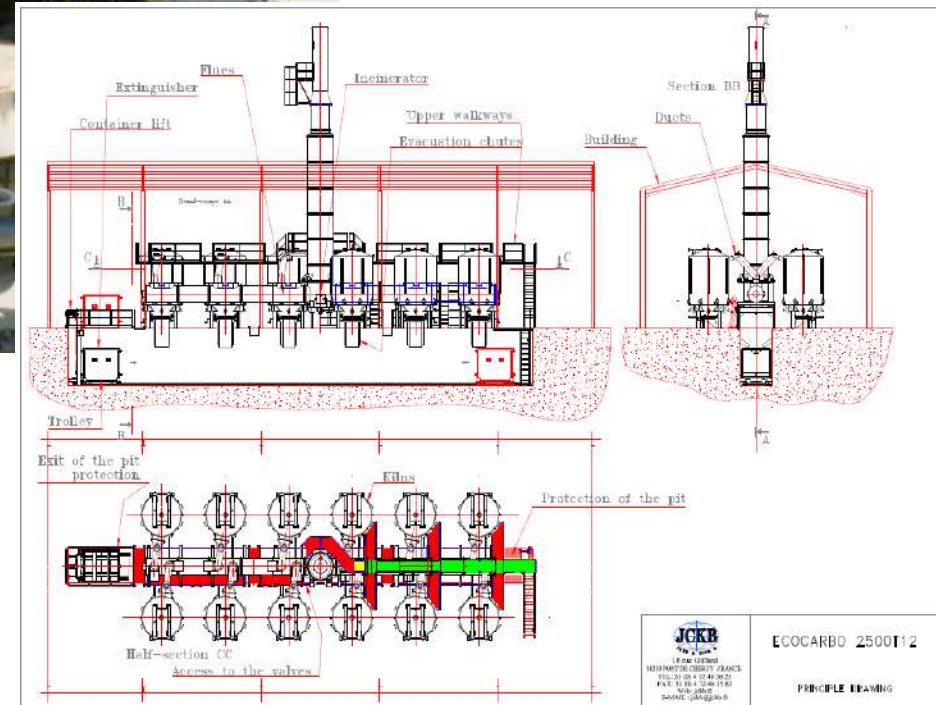


TRADITIONAL CHARCOAL MAKING AND POLLUTION





- Energy Recovery
- Emission Control
- Efficient use of feedstocks





TCP/CRO/3101 (A) Development of a sustainable charcoal industry

Second Announcement and Programme for the Expert Consultation

Sustainable Charcoal Production, Trade and Use in Europe

5 - 6 June 2007
Zagreb, Croatia

Jointly co-organised with Energy Institute Hrvoje Pozar



Supported by



Ministry of Agriculture, Forestry and Water
Management of the Republic of Croatia

www.drveniugljen.hr

2007



Food and Agriculture Organization
of the United Nations

THE CHARCOAL TRANSITION

Greening the charcoal value chain to mitigate climate change
and improve local livelihoods



2017

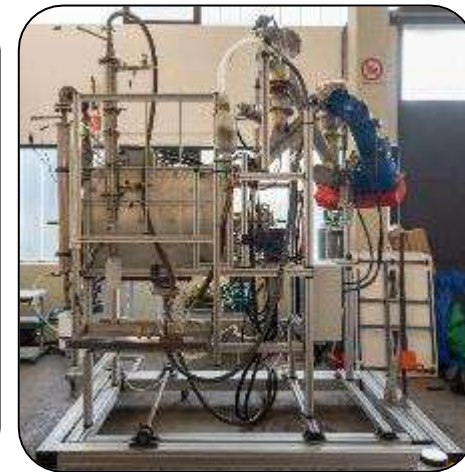


Biochar production facilities at Re-Cord

Rotary Kiln

Slow pyrolysis of biomass & waste to fuels and products

- Solid (as fuel or amendment) + high T heat
- Integration in large-scale Advanced Biofuel supply chain
- IN=100 kg/h



CarbOn RE-CORD

Slow pyrolysis of biomass for charcoal and biochar making.

- Fixed bed, Open-top Oxidative Reactor (Autothermal)
- Designed and developed for small farmers
- Continuous operation.
- IN=50 kg/h. OUT=12kg/h ($\eta_c = 24 \text{ wt.}\%$)



Intermediate pyrolysis
Pilot Demo Unit





Biochar Properties depends on various elements

- **FEEDSTOCK TYPE & CHARACTERISTICS**: MOISTURE, SIZE, ASHES, ETC.
- **PROCESS PARAMETERS**: MAX PROCESS TEMPERATURE (T_{MAX}), VAPOUR RESIDENCE TIME (VRT), SOLID RESIDENCE TIME (SRT), HEATING RATE (HR), ETC.

BIOCHAR IS A RATHER GENERAL TERM:

MANY SIMILAR BUT DIFFERENT PRODUCTS ARE CLASSIFIED AS BIOCHAR

THE SOLID PRODUCT DIFFER AS REGARDS:

- POROSITY
- ORGANIC CARBON AND ASH CONTENT (C_{ORG} , ASH)
- STABILITY (H/C_{MOL} , O/C_{MOL})
- PH
- FUNCTIONAL GROUPS ON BIOCHAR SURFACE (CEC-AEC)

THESE ELEMENTS DETERMINES THE EFFECTS OF THE BIOCHAR WHEN USED. THE BIOCHAR PERFORMANCE ARE ALSO VERY DIFFERENT DEPENDING ON THE TYPE OF SOIL

BIOCHAR & SOIL FERTILITY

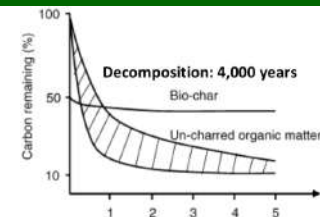
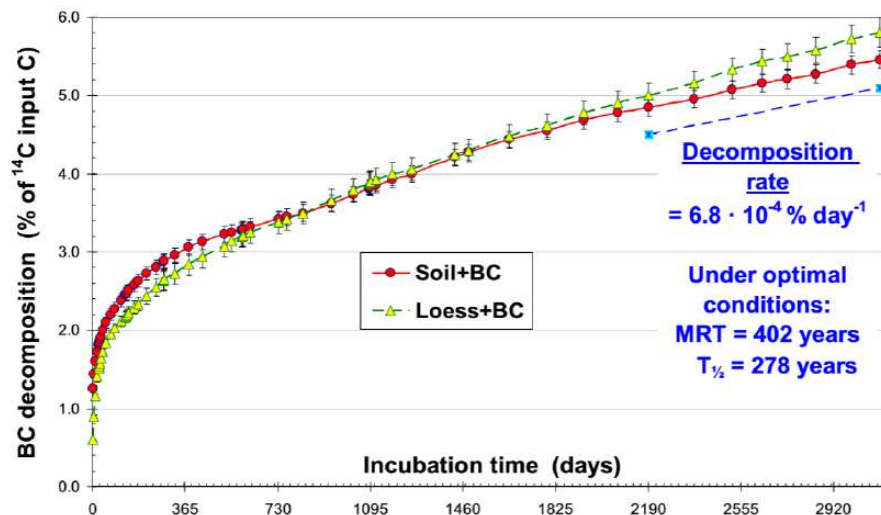
- Improvement of soil **physical** properties
 - *Mechanical structure*
 - *Soil porosity and aeration*
 - *Moisture retention capacity*
- Improvement of soil **chemical** properties
 - *pH increase in acidic soils*
 - *CEC and AEC*
 - *Improved N-cycle*
 - *Addition of C-recalcitrant to soil*
 - *Environment suitable for microorganism*
 - *Nutrient addition (slow release) and reduced leaching*
- Improvement of **biological** properties
 - *Effects strictly linked to the two previous ones*





BIOCHAR IS HIGHLY STABLE IN SOIL

AS DEMONSTRATED BY C-14 STUDIES



Y. Kuzyakov et al. / *Soil Biology & Biochemistry* 70 (2014) 229–236

Soil Biology & Biochemistry 70 (2014) 229–236



Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio



Biochar stability in soil: Decomposition during eight years and transformation as assessed by compound-specific ^{14}C analysis

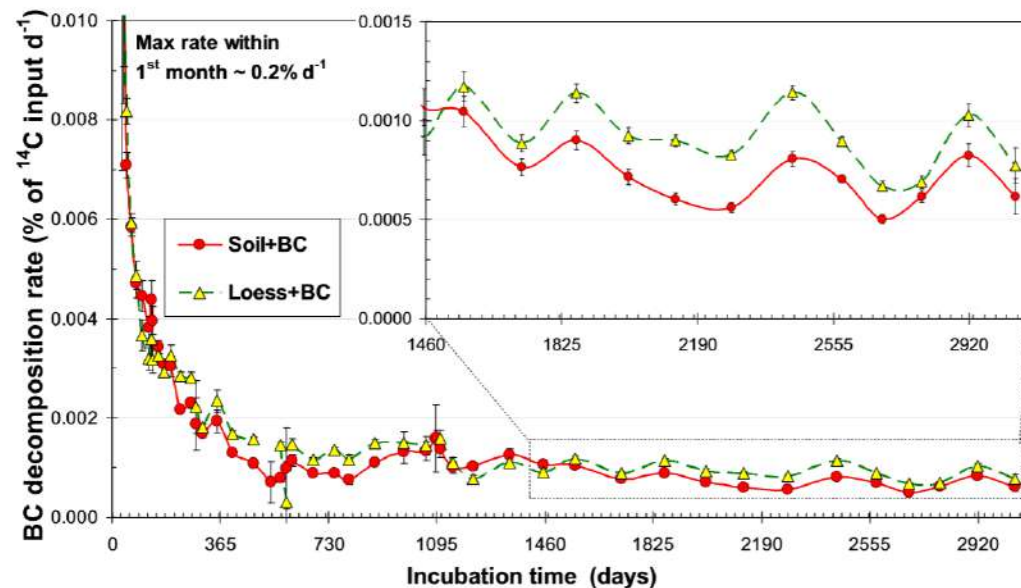
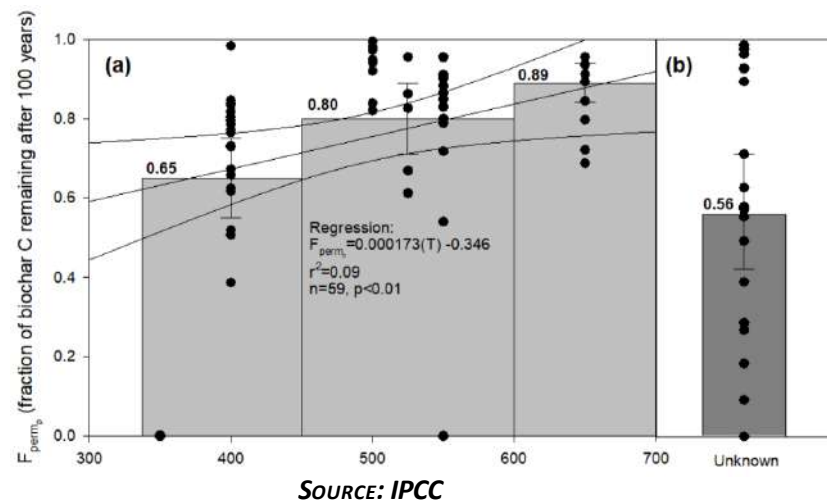


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IPCC LATEST REPORTS WELL ADDRESS BIOCHAR

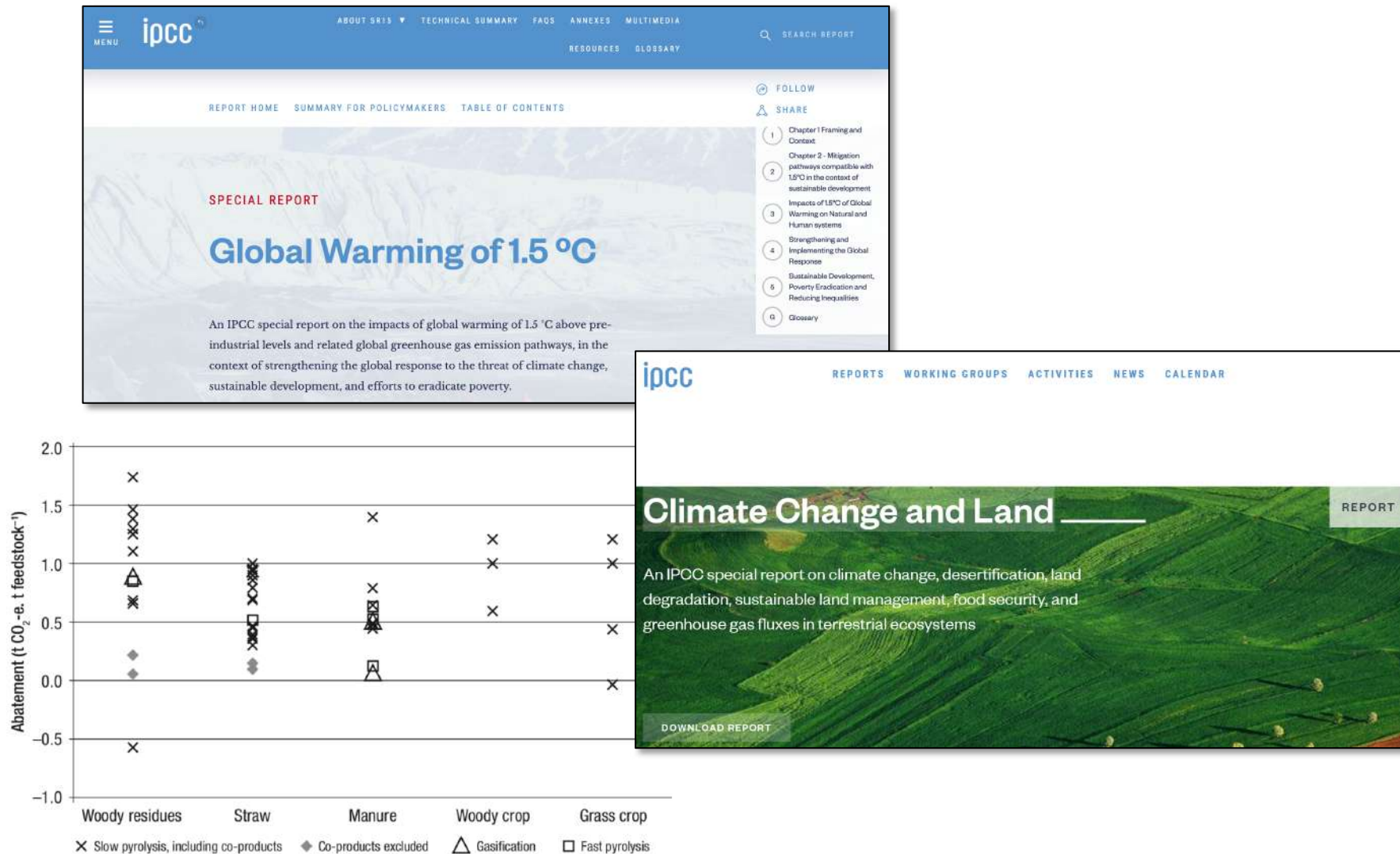


Figure 27.1 GHG abatement per unit of feedstock dry matter, for a range of feedstocks, from LCA studies. 'Manure' also includes biosolids and poultry litter. The data sources are indicated in Table 27.1



IPCC AND BIOCHAR: NEWLY DEVELOPED AND PUBLISHED ACCOUNTING FOR C-REMOVAL FROM BIOCHAR



GHG savings from biochar well documented by IPCC & other sources → Accounting is Possible

$\Delta BC_{Mineral}$ = the total change in carbon stocks of mineral soils associated with biochar amendment, tonnes sequestered C yr⁻¹

BC_{TOT_p} = the mass of biochar incorporated into mineral soil during the inventory year for each biochar production type p , tonnes biochar dry matter yr⁻¹

F_{C_p} = the organic carbon content of biochar for each production type p , tonnes C tonne⁻¹ biochar dry matter, Table 4A.1

F_{perm_p} = fraction of biochar carbon for each production type p remaining (unmineralised) after 100 years, tonnes sequestered C tonne⁻¹ biochar C, Table 4A.2

n = the number of different production types of biochar

EQUATION 4A.1

ANNUAL CHANGE IN BIOCHAR CARBON STOCK IN MINERAL SOILS RECEIVING BIOCHAR ADDITIONS

$$\Delta BC_{Mineral} = \sum_{p=1}^n \left(BC_{TOT_p} \cdot F_{C_p} \cdot F_{perm_p} \right)$$

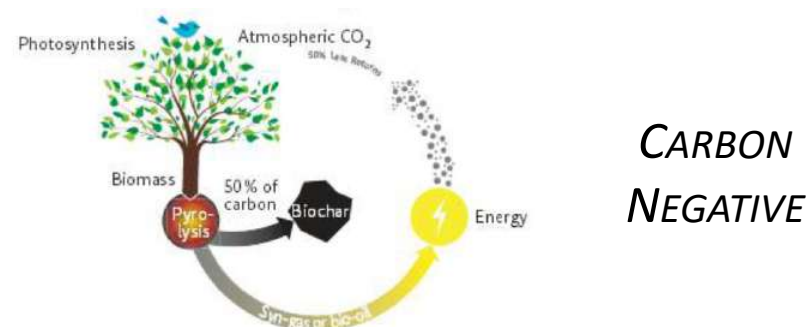
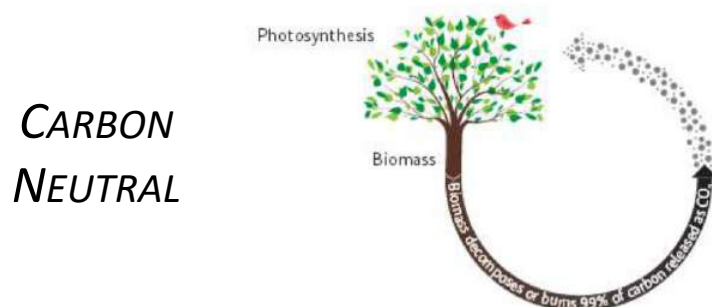
BIOCHAR TO OFFSET GHG EMISSIONS

Biochar to offset GHG emission is a **win-win-win-win** solution:

- Biochar deployable at large scale (land: 2nd C-sink after oceans): **huge CO₂ removal potential**: 1 t biochar → 3,66 t CO₂
- It is probably the **cheapest CO₂ offsetting option**
- It promotes **more sustainable agriculture** for food, feed, bioenergy, bioeconomy (**UN SDGs** → consensus)
- It support **climate change adaptation** of land (**EU Green Deal**)

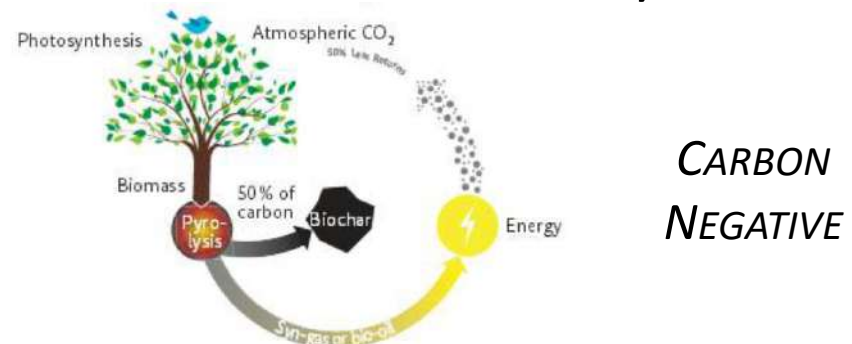
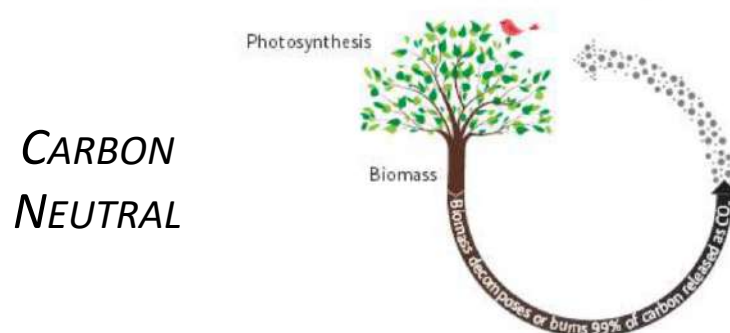
Moreover

- **Technology** is **mature** and available at many scales
- **C accounting** well developed at International level (**IPCC**)



AN EXAMPLE: SUSTAINABLE AVIATION

- **Biochar produced** from lignocellulosic residues
- **CO2 offset** through Biochar (measurable solution, thus evidence-based CO2 removal) → **C-removal form Biochar accounted** according to **IPCC rules**
- **Costs** for the action: **1/3rd-1/4th then SAF** (per tCO₂ saved)
- **Food, Feed, Energy and Products** from Biomass promoted
- **Consensus** is generated in Agriculture/Forestry
- The model can be well **combined with other sust.agricultural models** (as Agroforestry, Biogas Done Right, 4 pour mille initiative, FAO initiatives, etc)

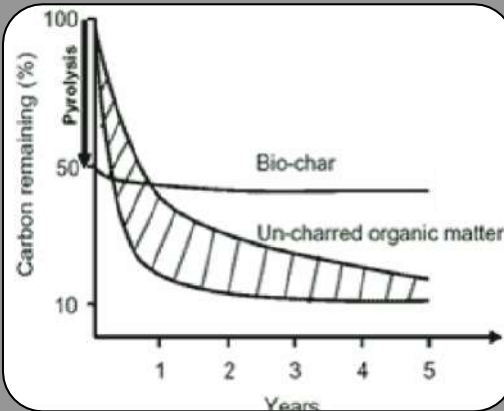




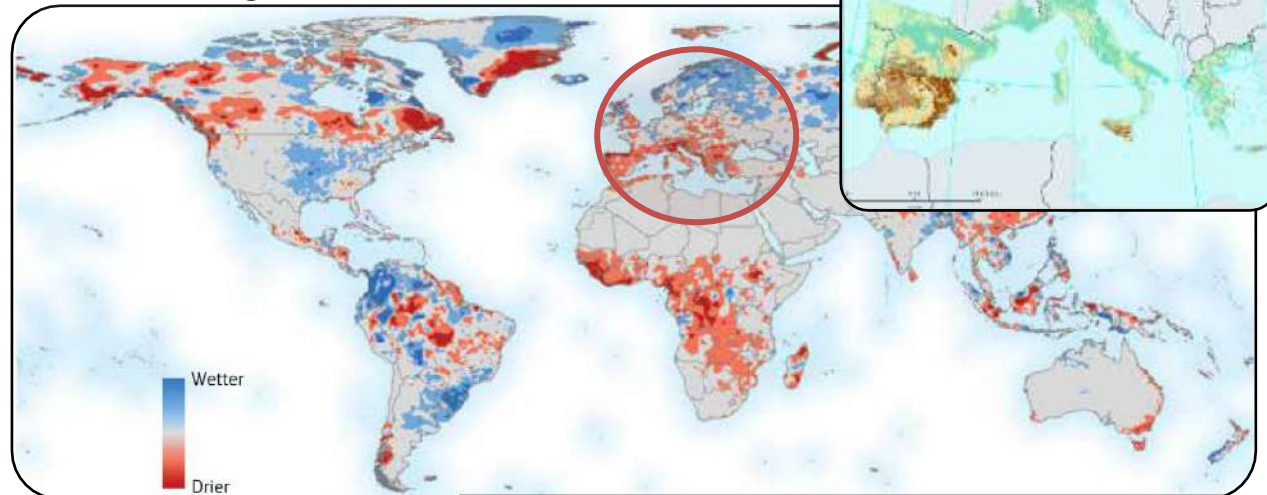
COM-BI for healthy soil, resilience to climate change and C sequestration



BIOCHAR sequesters C
(Climate Change Mitigation)



EU MED (PT, ES, FR, IT, HR, GR, CY):
8.5 Mha marginal lands (source: S2Biom project)



- **COMBI** produced, characterized and tested in two sites in Spain, in the framework of the H2020 BIO4A project on HEFA biojet (www.bio4a.eu)



Production and characterization of co-composted biochar and digestate from biomass anaerobic digestion

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Open Access

Abstract

Biochar, produced through pyrolysis of lignocellulosic biomass, is attracting increasing interest as soil amendment thanks to its potential numerous benefits to agriculture, as well as its ability to sequester carbon in soil. Solid fraction of digestate from anaerobic digestion is a well-known N-rich substrate, most often composted in large and small agro-industrial plants. Co-composting biochar and digestate has the potential to synergistically increase the agronomic value of both components; however, it needs further process and on-field research. The present research work reports on the experimental tests on producing biochar and co-composting various biochar amounts with digestate from biomass anaerobic digestion (product here named COMBI). Biochar was produced by feeding wood chips from chestnut to an innovative oxidative reactor. In order to evaluate the quality of the products obtained by composting and co-composting, correlating this with the final biochar rate in the material, the net organic matter yield, the humified organic matter, the compliance with the European Compost Network Quality Assurance Scheme (ECN-QAS) limits for inorganic pollutants, and the product stabilization and sanitization indexes were investigated. The 11.2% w/w d.b. biochar rate in the initial blend (19.8% w/w d.b final concentration in the co-composted products) offered the best performances and is recommended for further investigation. Additional benefits from co-composting were also assessed, as the reduced dust load that favors safety and health during logistics and use.

Keywords Biochar · Compost · Digestate · Co-composting · Soil amendment

1 Introduction

Sustainable production of biomethane is a key option to substitute conventional natural gas and decarbonize the energy system [1]: anaerobic digestion (AD) is the leading route to generate biogas, which can then be further upgraded to biomethane by CH₄ separation. Today, the AD process is a well-mature process, bringing environmental and social benefits at both local and global level [2, 3]: the main co-product of biomass anaerobic digestion is a sludge (digestate), which

can be applied to soil for agronomic purposes as an organic amendment. Composting is another well-known pathway to stabilize organic matter of various origins through a bio-oxidative process [4], which brings benefits as volume reduction, sanitization from pathogens, reduction of liquid contaminants, and economic and environmental returns [5, 6]. In anaerobic digestion plants, the composting stage of the solid fraction of digestate generally occupies large volumes and requires long residence time, in addition to complex logistical steps [7, 8]. The addition of a bulking agent in the compost pile is normally recommended, in particular when substrates as digestates are used. The small particle size of the material generates risks of anaerobic conditions within the pile, leading to the production of undesired phenomena as ammonia volatilization [9, 10].

Biochar is the solid product from lignocellulosic biomass pyrolysis, characterized by a high content of stable C, mostly produced through slow pyrolysis. Biochars from intermediate/fast pyrolysis and gasification are often discussed in literature, even if these show different characteristics. Biochar is a highly porous material with a wide range of possible uses, including

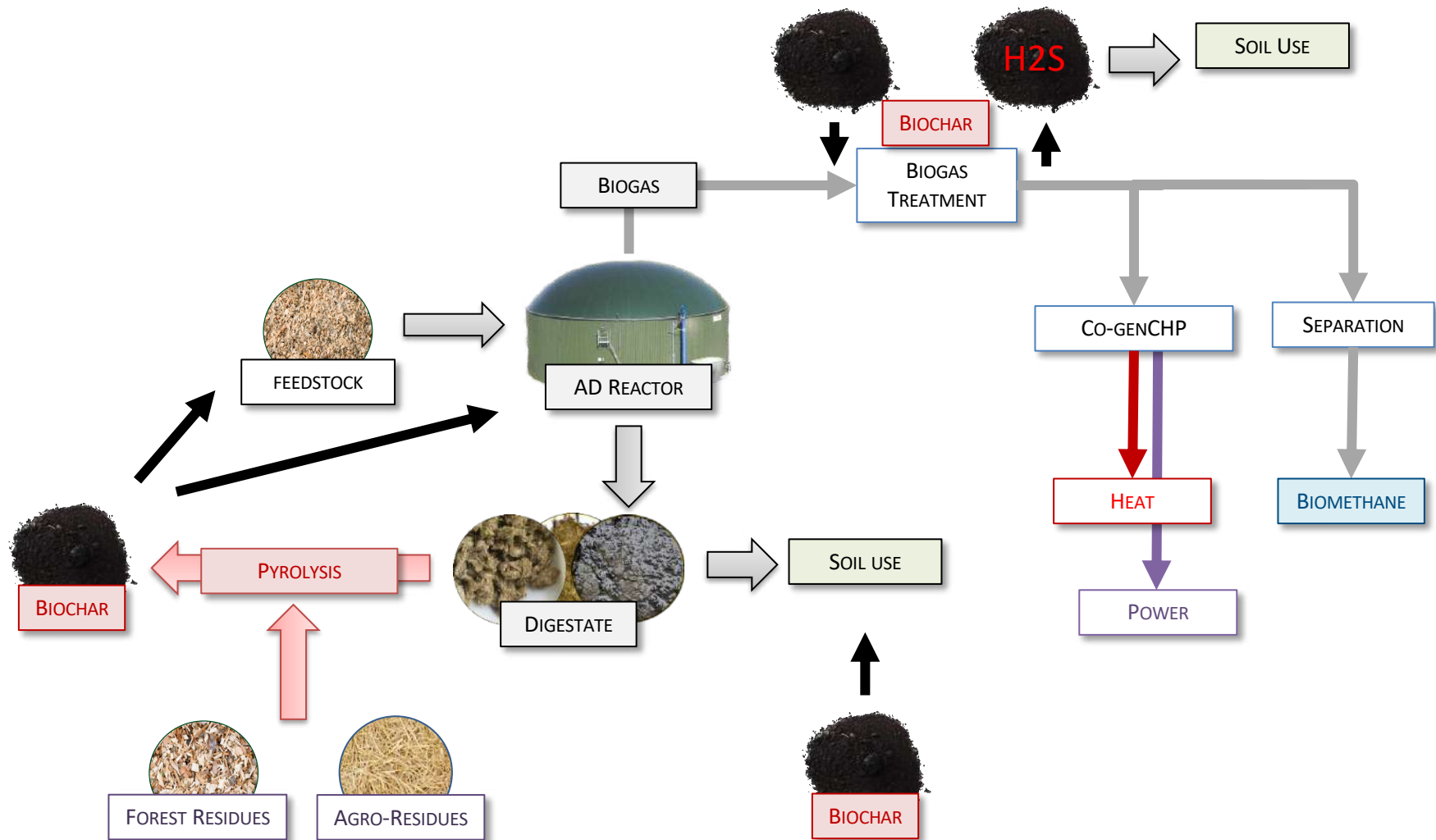
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BIOCHAR & ANAEROBIC DIGESTION

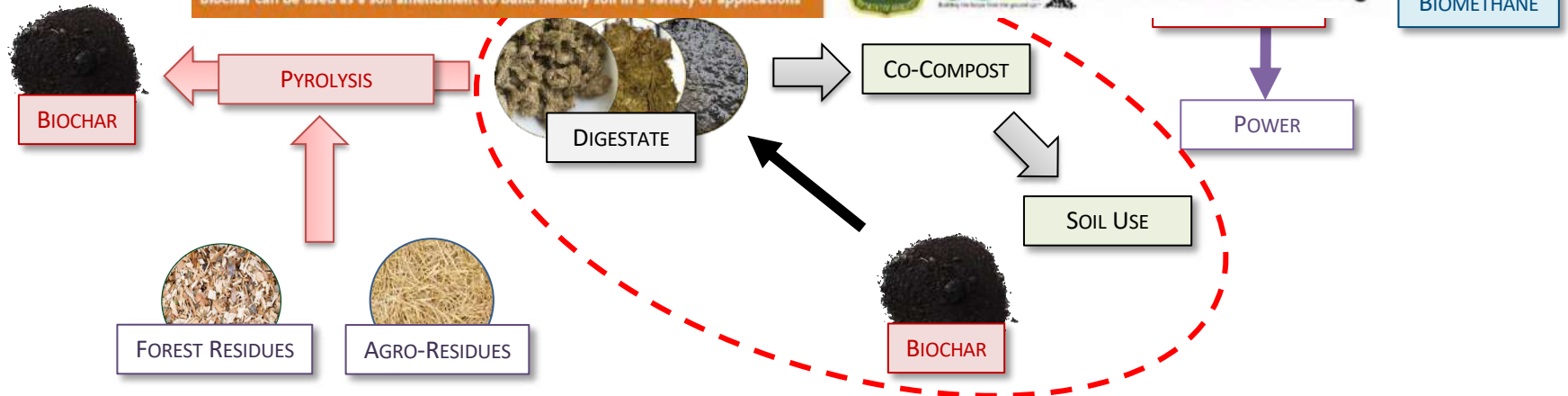


BIOCHAR & ANAEROBIC DIGESTION



AGRICULTURAL USES FOR BIOCHAR
Biochar can be used as a soil amendment to build healthy soil in a variety of applications

USDA USBI www.biochar-us.org LEARN MORE AT



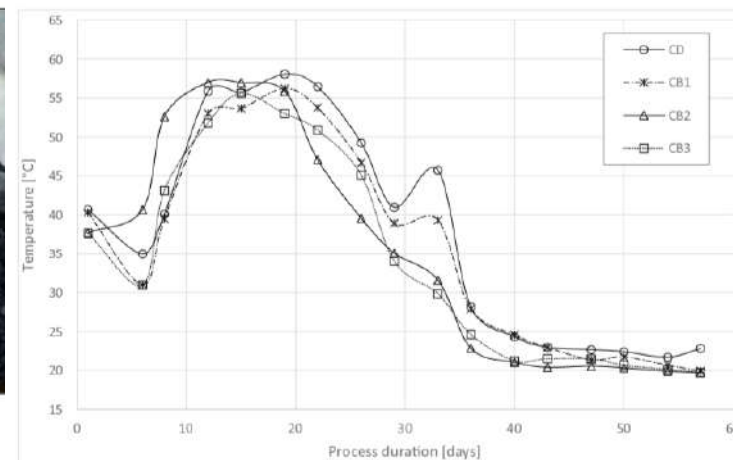


Table 2 Initial windrows compositions

	U.M.	CD	CB1	CB2	CB3
Windrow	kg d.b.	160.6	156.5	153.0	149.6
Starting moisture	% w/w w.b.	61.6	60.0	59.2	58.3
Biochar content	kg w.b.	0.0	12.0	18.0	24.0
Biochar rate	% w/w d.b.	0.0	7.3	11.2	15.2
C/N index		36.3	40.4	42.7	45.2

Biochar concentration in the final product:

14.9 - 19.8 - 22.8% w/w d.b.

- CB2 and CB3 completed the bio-oxidative phase about 4 days earlier than CD and CB1, keeping the same peak temp
- CB2 showed the lowest stabilization time, the highest degree of humification, and the lowest ammonium/nitrate ratio index
- CB3 was the only case with *E.Choli* proliferation

A

No fertilization	1	2	3	4
NPK	5	6	7	8
10% Biochar + Compost	9	10	11	12
15% Biochar + Compost	13	14	15	16
20% Biochar + Compost	17	18	19	20
100% Biochar + NPK	21	22	23	24
100% Compost	25	26	27	28

B

	Rep 1	Rep 2	Rep 3	Rep 4
1				
2				
3				
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Field trials: Ciudad Real (ES)

Background fertilization: 11/01/19

Seeding date: 14/01/19



No fertilization



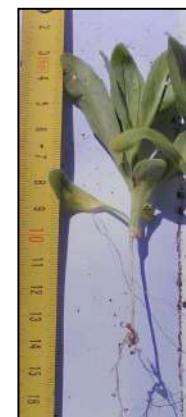
Mineral fertilization



100% Compost

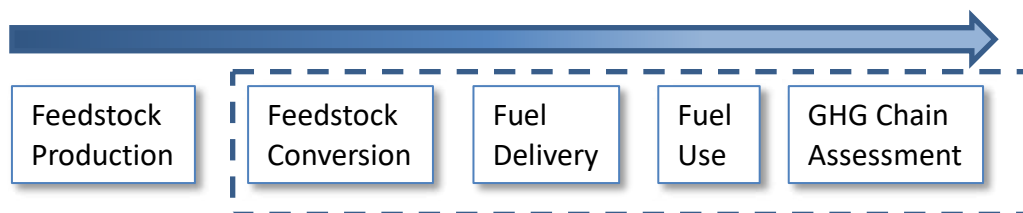


100% Biochar

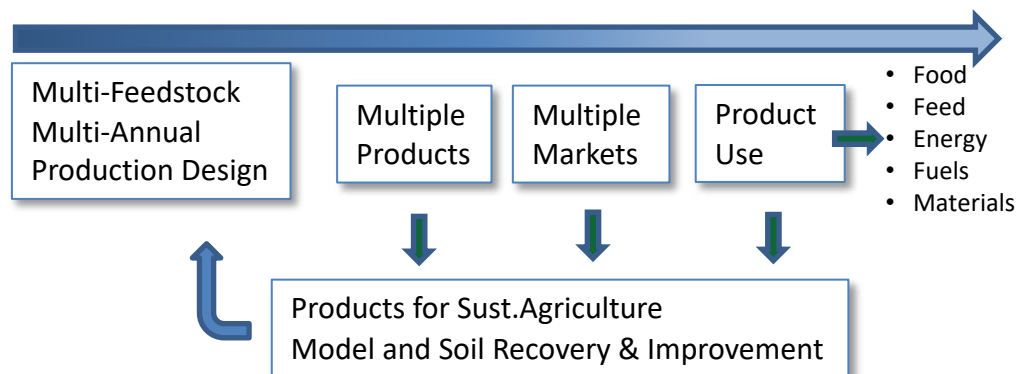


Biochar+ Compost 10%






How to make this linear biofuel thinking sustainable (GHG) enough?



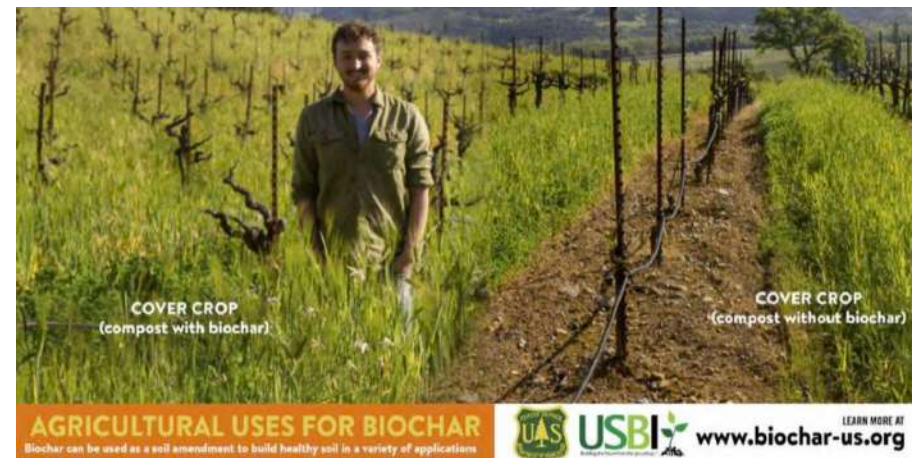
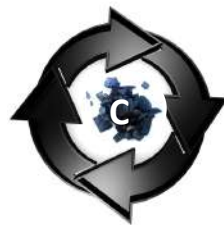

Which opportunities Bioenergy & Bioeconomy offer to make agriculture more sustainable (beyond GHGs, towards SDGs)?

From linear to circular, from energy-driven to sustain.agricultural models

Bioenergy / Bioeconomy can make Sustainable Agriculture possible

BIOCHAR & BIOMASS VALUE CHAINS

- **Slow Pyrolysis integrated in Biofuel chains:**
 - ✓ *Providing heat for biomass treatment or power*
 - ✓ *Providing char to thermochemical conversion or as soil amendment*
 - ✓ *Decentralized: easily sizeable to the bioenergy/bioprocess chain*
- **Bioenergy/Biofuels & Sustainable Agriculture**
 - ✓ *Long-term shift from fossil-based to sustainable bio-based agriculture*
- **Bioenergy Supported Sustainable Agriculture**
 - ✓ *Value chains revised to embrace the **multi-annual dynamic nature of agriculture**. **Multi-year land management, rotation, agroforestry, etc***
 - ✓ ***Food, feed, energy, products.***
 - ✓ ***There is one agricultural system only!***



THUS... IS CO-COMPOSTING WORTH?

- If the amount (tons) of biochar in co-composting or blend is the same → no major difference in sequestered fixed C, no strong motivations for co-composting from the C-value economic point of view. Therefore:

→ ***Does co-composting pay off, or is instead blending sufficient and a better economic choice?***

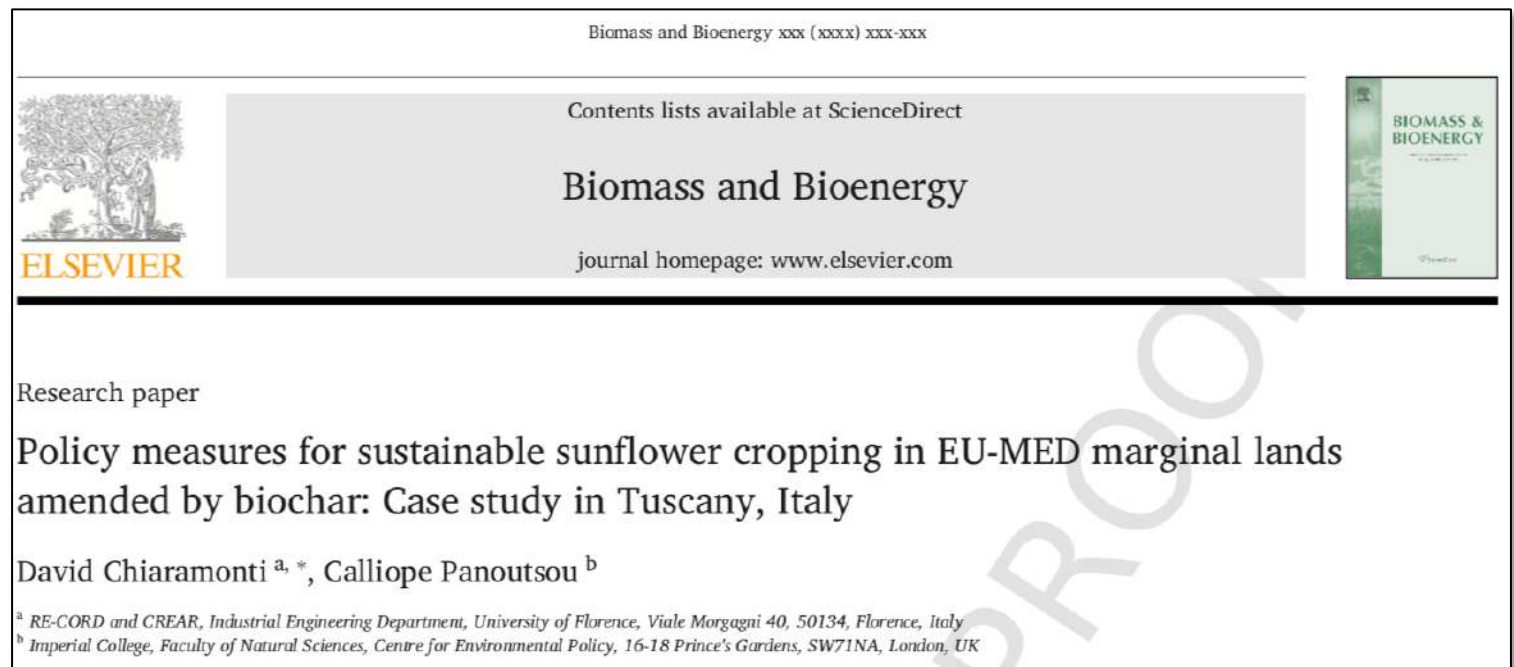
- Answering this question is **site- and policy-dependent**, and requires extensive further work.
- AD plants (expecially OFMSW AD) largely implement ***pasteurization step*** → thus **composting not strictly needed** from the sanitary point of view

THUS... IS CO-COMPOSTING WORTH?

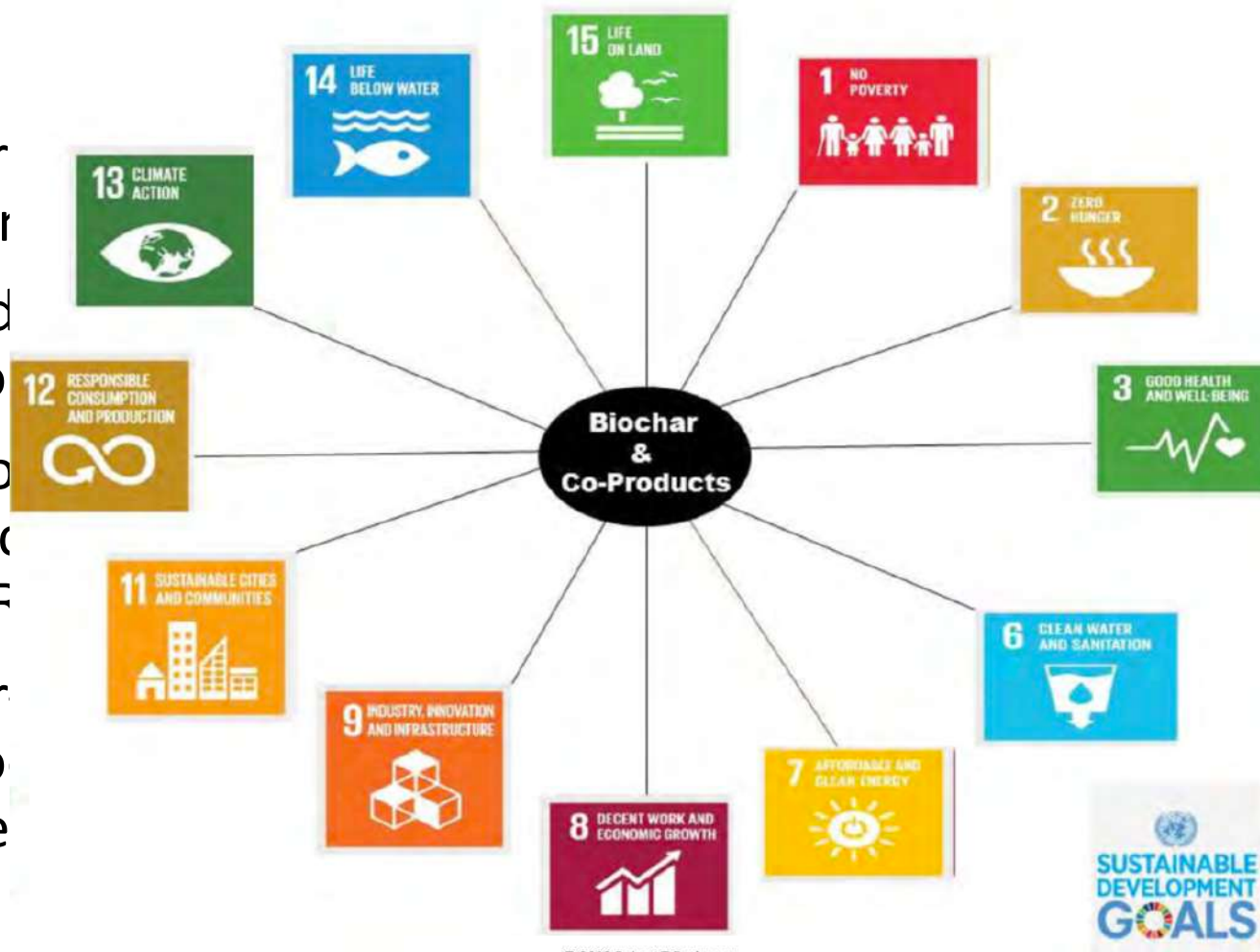


- If thus digestate can be directly spread on soil, avoiding composting save CAPEX and OPEX. **Blend will most likely be the preferred choice**
- **If composting process acceleration is instead required, adding Biochar could be an option.** This could be the case of some OFMSW composting units.
- If **biochar deployment (dust)** is an issue, **co-composting will help** (but other options are possible)
- **Detailed analysis of local (soil) benefits from collected nutrients favour co-composting**, but customer must pay for this (market to be developed).

- The deployment of biochar, biochar & compost and COMBI will necessarily be a **policy-driven issue** (EU: LULUCF in CAP)
- **Multiple policies** could interact impact. Studies needed to provide policy makers with recommendations. e.g. :



- Biochar fields are
- Bioproducts (Bioeconomy)
- Thermochemical processes synergistic with future F
- Biochar feedstocks to achieve



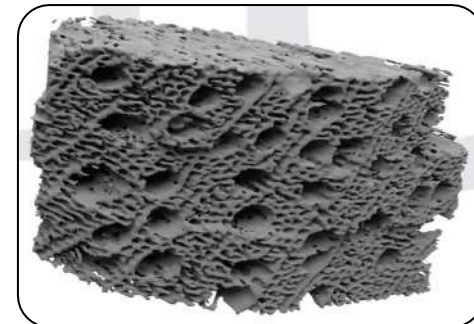
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**Bioenergy/Bioeconomy supported
Sustainable Agriculture**

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Source: Luke, Finland.